ENHANCEMENT OF FLOW IN PIPELINE TRANSPORTATION FOR CRUDE OIL EMULSION

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ABSTRACT

This study presents the flow enhancement of crude oil in pipeline transportation using emulsion. High viscosity and low pour point of crude oil often hinder transportation from processing wells to the enhanced oil recovery reservoir. Therefore, a stable oil-in-water emulsion is desired, by comparing different types of surfactant. Demulsification process too is necessary to separate the oil in water. Emulsion was prepared using Span 80, Span 83, and Triton X-100 each respectively in a ratio of 70-30% o/w and 50-50% o/w. Parameters include varying mixing speed in emulsion preparation, temperature and rheological properties of the emulsion were studied by carrying out stability tests. Interfacial properties such as surface tension and interfacial tension of the emulsion were also measured. The effect of droplet diameter with surfactant concentration in the emulsion was also studied. The most stable emulsion was used for transportation in a 3meter pipeline. Rheological data on the emulsion was used to correlate to the laminar flow during transportation. Three demulsifiers: dioctylamine, cocoamine, hexylamine were used to compare for their effectiveness in demulsification. The study reveals that the stability of o/w emulsion increases when an anionic surfactant, Span 83, was used. By increasing the oil content, the speed and mixing temperature resulted in an increased emulsion stability, and a reduced droplet diameter. Dioctylamine proved to be the best demulsifier among cocoamine and hexylamine.

ABSTRAK

Kajian membentangkan peningkatan aliran minyak mentah dalam saluran pai pengangkutan menggunakan emulsi. Kelikatan yang tinggi minyak mentah sering menghindar pengangkutan dari pemprosesan telaga ke pumulihan takungan minyak. Oleh itu, emulsi minyak dalam air yang stabil adalah diingini. Emulsi disediakan dengan perbandingan antara tiga jenis ‘surfactant’. Span 80, Span 83, dan Triton X-100 digunakan sebagai ‘surfactant’ dengan mengguna nisbah 70-30% minyak/air dan 50/50% minyak air. Parameter yang dikaji termasuk kelajuan semasa menghasil emulsi, suhu dan sifat reologi untuk menguji kestabilan emulsi. Ketegangan antara emulsi dan saiz titisan emulsi juga dikaji. Emulsi yang paling stabil digunakan untuk diangkut dalam paip berpanjangan 3meter. Data reologi emulsi digunakan untuk mendapat jenis pengaliran emulsi. Akhirnya, tiga demulsifier (dioctylamine, cocoamine dan hexylamine) digunakan untuk membanding keberkesanan dalam memisahkan emulsi. Kajian menunjukkan kestabilan minyak/air meningkat apabila ‘surfactant’ berionik, Span 83, digunakan. Dengan meningkatkan kandungan minyak, kelajuan dan suhu pencampuran akan memberikan emulsi yang lebih stabil. Emulsi jenis laminar ditunjukkan semasa pengangkutan melalui paip. Dioctylamine dibuktikan merupakan demulsifier yang terbaik antara cocoamine dan hexylamine.

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LIST OF SYMBOLS

O/W	-	oil-in-water emulsion
W/O	-	water-in-oil emulsion
O/W/O	-	oil-in-water-in-oil emulsion
W/O/W	-	water-in-oil-in-water emulsion
Q	-	volumetric flow rate (m^3/s)
Re	-	Reynolds number
T	-	temperature (^0C)
μ	-	viscosity ($N.s/m^2$)
ρ	-	density (kg/m^3)
v	-	mean velocity
D	-	diameter of pipe (m)
MSDS	-	Material Safety Data Sheet

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Oil transportation has always been a complex and highly technical operation. Since crude oil accounts a large fraction of the world's potentially recoverable oil reserves, thus puts them in the frontline of the energy resources. Proper scheduling of crude oil transportation presents vast economic potential. Therefore this thesis presents the art of transporting crude oil through a pipeline system which is designed to deliver quantities of crude oil from the production area to the refinery. The transportation of materials by pipeline can be substantially more economical than by means of shipping, which involves a relatively long distance of pipeline for transportation. Also, an extensive application of pipeline procedures can be applied through the movement of commercial crude oil to a distant market where it can be marketed and consumed.

Several alternative transportation methods for heavy crudes have been suggested and engaged, including preheating of the crude oil with continuous heating of the pipeline, dilution with lighter crude oils, and partial upgrading. (S.N.Ashrafizadeh & M.Kamran, 2010). These above-mentioned methods experience logistic, technical, or economic drawback.

Currently, we only consider one general approach in transporting the heavy oil, i.e. by viscosity reduction (Peter & Pilehvari, 1993). . Reduction of oil's viscosity can be accomplished by many methods. Modern researchers constantly seek ways to apply emulsions to improve the transport of crude oil, as well as study methods of minimizing production problems caused by emulsions. Increasing offshore oil and gas exploration and production resulted in the transportation of well fluids in pipelines over relatively long distance.

A recent review by Rafael et.al (2010) states that O/W emulsions are deliberately produced to reduce the viscosity of highly viscous heavy crudes so they can be transported easily through the pipeline. This efficient way is achieved with the help of surfactant agents. The stability of crude oil is favored by the concentration of surfactants which contribute to decrease the interfacial tension between the crude oil and water. In this way, crude oil is transported in the form of fine crude oil droplets in a continuous phase comprising water as the main component. Water-in-oil emulsions can be made that contain high doses of oil. The viscosity of these emulsions is much lower than the viscosity of the crude oil and relatively uninfluenced by the oil type. “Oil-in-water emulsions with oil concentrations great enough to be of economic interest are possible, and the diluents (water) is usually cheap and easily disposed or recycled”. (Peter & Pilehvari, 1993).

In order to transport the crude oil emulsion systems, the first 3 steps are conducted, which are, producing the oil-in-water emulsions, transportation of produced O/W emulsions to the desired destination and finally separation of oil and water phases. The paper focuses on the pipeline transportation that is particularly challenged by the high viscosity of heavy oils and low mobility. Since the viscosity of the crude oils is the major factor of obstructing pipeline transport, a cheap, environmentally acceptable method must be found to lower the viscosity (Peter & Pilehvari, 1993).

1.2 PROBLEM STATEMENT

Fluid extracted from the wells is difficult to handle through pipelines by normal pumping means. The major setback of transportation is due to the high viscosity and low pour point of the crude oil. This is especially discerning with an increase of offshore activity of oil exploration and production. Consequently, special heating units installed in the pumping stations along the route of the pipeline is being used. These oil heaters would burn night and day to maintain pumpable fluidity of the crude oil. However, this method is not favorable since it is not economical by having the need to increase energy consumption.

Also, present issues like instability of asphaltenes, paraffin precipitation and high viscosity that cause multiphase flow, clogging of pipes, high-pressure drops, and production stops, contributes to the problem of transporting using pipeline. The high concentrations of sulfur and several metals, particularly nickel and vanadium (Shadi W. Hasan, 2010) hinder the crude oil from being pumped through the pipeline.

Therefore it is crucial to determine a novel method to enhance the crude oil transportation in the pipeline. This is so as to increase the oil mobility of viscous oils, while reducing its viscosity (Yousef, George, Elgibaly, & Elkamel, 2004).

1.3 RESEARCH OBJECTIVE

The objective of this thesis is to improve crude oil transportation by using oil in water emulsion. Rheological properties and characteristics of its emulsion were investigated in order to improve flow. Accuracy and reproducibility in obtaining the data for design and analysis is aimed throughout the research of transporting oil through pipeline.

1.4 SCOPE OF STUDY

i. Characterization of O/W emulsions in terms of chemical and physical properties i.e. stability of emulsions, shear stress, shear rate, dynamic viscosity, rotations per minute(rpm), temperature, surface tension, interfacial tension(IFT),

ii. Facilitating the handling and transporting the crude oil emulsion system includes producing the oil-in-water emulsions and transportation of produced O/W emulsions in a simulated pipeline.

iii. The study also aims to determine a suitable demulsifier for separation of oil and water phases after the emulsion is transported.

v. To provide an improved method of handling and transporting the crude oil at low pumping costs and under reduced friction conditions.

1.5 RATIONALE AND SIGNIFICANCE

A simple and cost effective surfactant will be proposed in producing O/W emulsion in lab simulation. The characteristics and behavior of O/W crude studied will provide better understanding of emulsion in pipeline.

A generic solution for crude oil transportation will provide useful aid of transportation of crude using pipeline in the petroleum industry.

CHAPTER 2

LITERATURE REVIEW

This chapter gives justification on why O/W emulsions are selected to be studied over other methods of transportation. It also reviews about the stability and surfactants normally used in the emulsions.

2.1 PHYSICAL PROPERTIES OF CRUDE OIL

Knowledge on the physical properties or classification of crude oil compound is important. This is so as to optimize its performance in a refinery and to produce the correct range of products for a particular market.

Crude oil refers to conventional crude oil. It exists as a liquid mixture in natural underground reservoirs and at atmospheric pressures. Conventional crude usually ranges from 20 to 40 API density gravity.

Property	Value
Specific gravity at 60˚F	0.946g/cm^3
API gravity	18
Dynamic viscosity	2000cP
Reid vapor pressure	4.3psi

Table 2.1 Sample physical properties of Geisium crude oil((Zaki, 1996)

Crude oil	Country	API gravity(˚)	% wt sulfur
Sahara Blend	Algeria	47	0.11
Minas	Indonesia	35	0.08
Iran Heavy	Iran	30	2.0
Basra Light	Iraq	30.2	2.6
Kuwait	Kuwait	31	2.63
Es Sider	Libya	36.6	0.42
Bonny Light	Nigeria	34.3	0.15
Qatar Marine	Qatar	35	1.6
Arab Light	Saudi Arabia	33.4	1.8
Murban	UAE	39	0.9
BCF 17	Venezuela	16.5	2.5

Table 2.2 OPEC –Organization of the Petroleum Exporting Countries basket after June 2005 (Vassiliou, 2009)

i. Specific gravity

Sometimes referred to as “relative density” in modern scientific usage, it is the ratio of weight of crude oil at a given temperature and volume relative to the weight of the equal volume of water at the same temperature. (Oil & Gas Field Technical Terms Glossary, 2007-2010). The density of oils may vary depending on the field of origin produced, as oils tend to become lighter with depth due to the higher quantities of light paraffin.

ii. Viscosity

Heavy oil generally has a viscosity between 1,000 and 10,000 centipoise(cP), while conventional crudes’ viscosities range between 10 and 100cP. (Vassiliou, 2009). Generally, viscosity and specific gravity of oils are related directly to each other and vary with the composition of oil. Oil having a higher average molecule weight will also have a higher specific gravity and viscosity.

iii. Pour point

Pour point is the temperature where the oil will not flow in a definite manner. It relates with an indication of property of oil at low temperatures and an estimation of the amount of paraffin wax. If no paraffin wax is present in the oil, its pour point would depend on the viscosity of the crude oil (Oil & Gas Field Technical Terms Glossary, 2007-2010).

2.2 CHEMICAL PROPERTIES OF CRUDE OIL

Petroleum contains 4 groups of hydrocarbons, i.e. alkane or paraffin, cycloalkanes or napthenes, aromatic and naphthenoaromatics or complex hydrocarbon. Crude oil contains between 15% to 20% of alkanes. It may rise to as high as 35% in very paraffinic crude oil or drop to 0 in heavy biodegraded oil (Kinghorn, 1983).

Characteristics	Value	Experimental method
Saturated	34.22wt%	SARA
Aromatics	38.82wt%	SARA
Resins	19.96wt%	SARA
Asphaltenes	6.58wt%	SARA
Wax appearance and temperature	122˚F	Viscosity
Wax	3.56wt%	HV-237

Table 2.3 Composition of West Paydar crude oil (S.N.Ashrafizadeh & M.Kamran, 2010)

Non-hydrocarbons in petroleum are sulfur compounds, oxygen compounds, nitrogen compounds, and metallic compounds.

Sulfur compounds make up the largest group of non-hydrocarbons in petroleum, such as H_2S, mercaptan, alkylsulfides like allylsulfide and thiobenzene. Generally, the quantity of sulfur increases as the density of the crude oil increases or API gravity decreases. They are commonly found in petroleum distillates or in distillation residue.

The sulfur compounds must be destroyed or removed as it can poison the metallic catalyst during the refining process (McCain, 1990).

As for oxygen compounds occurring in petroleum, its amount is usually less than 2%. In cases where oxygen content is reported to be higher than the usual, it may have been the oil has suffered prolonged exposure to the atmosphere either during or after production. It may also be that the increase of the boiling point of the fraction resulted in higher oxygen content (McCain, 1990).

Generally, nitrogen content in petroleum is low and falls within the range 0.1 to 2.0%. It is common to detect trace amounts of nitrogen, in higher asphaltenes in oil will have higher nitrogen content(Neumann, Lahme, & Severin, 1981).

Metallic compounds occur in very small concentration, therefore is called trace metals. They could be inorganic salts, metal soaps, organic metal-complex compounds. Their nature and their abundances in crude oil can provide information as to the origin, migration and maturation of petroleum while providing a basis for regional geochemical prospect. Its nature has now become the interest for refinery operator and environmentalist who are concerned with the emissions from oil-fired power plants. Nickel and vanadium are most common, but ferum, zinc, chromium, mangan, cobalt and others are almost always present (McCain, 1990).

2.3 METHODS OF TRANSPORTATION

According to (Sanier, Henaut, & Argilier, 2004), heavy crude oils cannot be transported with conventional pipelines due to their high viscosity. Additional treatments are required to reduce the viscosity or in lowering the friction in the pipe.

2.3.1 Dilution Method

Dilution of heavy crude oil by addition of lighter liquid hydrocarbons, usually condensates from natural gas production, or lighter crude oils are methods used since the 1930s to reduce the viscosity of heavy oils. According to Shadi W. Hasan(2010), at 25˚C, the presence of 20% of light crude oil within the heavy crude oil phase causes 96% viscosity reduction using Canadian crude. However it may require considerable investments in pumping and pipelines due to the increase of the transport volume and the need to separate the solvent, process it and then returning it to the oil production site. Also, as high as 30% volume of diluents are used to meet the API gravity specification. Special attention must be paid to asphaltene and paraffins stability, since condensate or light oil addition would cause precipitation and pipeline clogging. From past experience, heavy oil dilution may reduce viscosity but other issues remain unsolved like asphaltene and paraffin deposition (Rafael, et al., 2010). Recycling of diluents might be solution but it requires large investment in installing an extra pipeline. (Sanier, et. al.,2004)

2.3.2 Partial Upgrading Method

The heavy crude is being upgraded into a lighter crude. (Sanier, Henaut, & Argilier, 2004). This method consists of altering the composition of heavy oils to make them less viscous. According to Saniere(2004), traditional hydrotreating process, deasphalting process Solvahl, thermal treatment Tervahl process and catalytic hydrotreatment Hyvahl processes can be used in this application.

2.3.3 Heating Method

Heating is common for ameliorating the flow properties of heavy crude oil. With increasing temperature, viscosity decreases swiftly (Sanier et. al.,2004). It is important to heat the oil to a point where the oil has a substantially reduced viscosity. Shadi W. Hasan (2010) found that heavy crude viscosity decreases significantly from 10.0 to 2.5 Pa s when the temperature changes from 25˚C to 75˚C. However, the design of a heated pipeline needs much effort as it involves consideration on expansion of the pipelines, number of pumping/heating stations, and heat loss. The principle drawbacks are the high capital and operational cost of heating the pipeline over an extended distance (Shadi W. Hasan, 2010). A greater corrosion rate of the internal pipe will occur due to the temperature increase (Guevera, 1998). The method is not feasible to be applied in underwater pipeline transportation of heavy oil through a heated pipeline due to the cooling effect of the surrounding water (Shadi W. Hasan, 2010). In addition, his study showed that heating could induce changes in the colloidal structure of the crude oils and worsen their rheological properties. Considerable amounts of energy are used in the heating method and diluents prove to encounter logistic problems.

2.3.4 Oil-in-Water emulsion

In this method, with the help of suitable surfactants the oil phase becomes dispersed in the water phase and stable oil-in-water emulsions are produced . This consequently results in a significant reduction in the oil viscosity with a viscosity range of about 50-200cP. This method is useful in transporting crude oils with viscosities higher than 1000cP particularly in cold regions. According to Poynter(1970), another advantage would be, since water is the continuous phase, crude oil would have no contact with the pipe wall, thus significantly reduces pipe corrosion (for crudes with high sulfur content) and also preventing the formation of sediments in pipes (for crudes with high asphaltene content). Restarting of pipeline after emergency shutdown and reemulsification of oil may not pose major problems.

2.3.5 Core annular flow

This method of transportation is where a water film surrounds the oil core and acts as a lubricant. Water fractions of 10-30% are typically used. Addition of chemicals such as sodium hexametaphosphate to the water increases the water's ability to adhere to the pipe and displace the oil films without forming an emulsion (Rafael, et. al, 2010). Configuration of this method is stable but the oils tend to adhere to the wall, leading to restriction and an eventual blockage of the flow system. For normal pumping operation of crude oil, interruptions are expected in the process because of mechanical failure, power interruptions and ruptures in the pipeline or climate conditions. When annular flow is used as a form of transportation, interruptions in the operation even in short periods of time can result in stratification of the two phases. The difficulty is even exacerbated during a shutdown operation allowing stratification of oil and water phases requiring a large restart pressure. (Sanier, Henaut, & Argilier, 2004) In attempt to restore the annular flow by pumping simultaneously, a multiphase system with different viscosities creates peaks in the discharge pressure of pumps or along the pipeline. This will then exceed the maximum allowable pressure because of large pressure peaks (Rafael, et al., 2010).

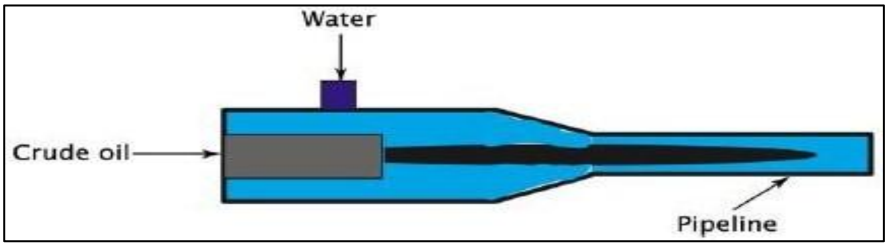

Figure 2.1 Pipeline design allowing core flow of heavy oils (Rafael, et al., 2010)

In short, O/W emulsion is a reliable option method chose to be studied because of the activation of natural surfactants occurring in heavy and extra heavy crudes (Rafael, et. al., 2010). Generally, non-ionic surfactants would be a good choice because they are not affected by the salinity of water, other than being relatively cheap and undesirable organic residues that may affect the oil properties are avoided.

2.4 TYPES OF EMULSION

In any oil and water phases, the type of emulsion formed relies on several factors. When the volume fraction of one phase is very small compared to the other, the phase that has the smaller fraction is the dispersed phase while the other is the continuous phase. If the volume-phase ratio is close to 1(50:50 ratio) then other factors shall determine the type of emulsion formed (Kokal, 1995).

2.4.1 Water-in-oil

Water-in-oil emulsions consist of water droplets in a continuous oil phase that is commonly found in the oil industry.

2.4.2 Oil-in-water

Oil-in-water emulsions are sometimes referred to as “reverse” emulsions (Kokal, 1995). Viscosity of O/W emulsions were found to increase as the oil content of the emulsion increased to 60% in sample crude oil. The oil content that increase beyond this value causes a sudden increase in the emulsion viscosity. At this point, phase inversion to W/O emulsions occur. Therefore, emulsions made with oil contents higher than 60% is not suitable to make O/W emulsions (Rafael, et al., 2010).

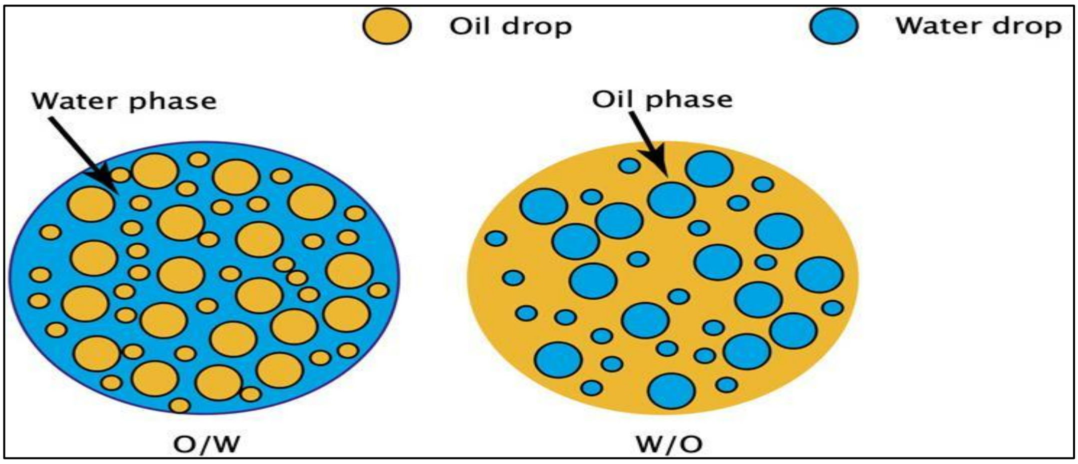

Figure 2.2 Emulsions found in petroleum transportation (Rafael, et al., 2010)

2.4.3 Multiple Emulsion

Multiple emulsions are more complex and consist of tiny droplets suspended in larger droplets that are suspended in a continuous phase. Taking the example of a water-in-oil-in-water emulsion, it consists of water droplets suspended in larger oil droplets that, again, are suspended in a continuous water phase (Kokal, 1995).